

PACKAGING OF ELECTRONIC CHIPS WITH AIR-BRIDGE STRUCTURES

Field of the Invention

5 This invention relates to the packaging of electronic chips, and more particularly to the packaging of electronic chips having air-bridge structures.

Background of the Invention

10 As the density of devices, such as resistors, capacitors, and transistors, in an integrated circuit is increased, the distance between the signal carrying conductors is decreased, and the capacitive coupling between the conductors is increased. Several problems result from the increased capacitive coupling. First, the increased capacitive coupling reduces the rate at which information can be transferred along each of the signal carrying conductors. Second, the increased capacitive coupling between the signal carrying conductors reduces the noise margin on the conductors. In the worst case, a
15 signal on one signal carrying conductor is capacitively coupled to an adjacent signal carrying conductor, and the information on the adjacent conductor is destroyed. Since it is desirable to avoid destroying information, it is also desirable to reduce the capacitive coupling between the signal carrying conductors of an integrated circuit.

20 In an integrated circuit, decreasing the dielectric constant of an insulator that separates two adjacent signal carrying conductors reduces the capacitive coupling between the two adjacent signal carrying conductors. Silicon dioxide is the most commonly used insulator in the fabrication of integrated circuits and has a relatively high dielectric constant of about four. Carbon dioxide has a smaller dielectric constant than silicon dioxide, so replacing silicon dioxide with carbon dioxide reduces the capacitive
25 coupling between the two adjacent conductors. Unfortunately, the thermal conductivity of carbon dioxide is much less than the thermal conductivity of silicon dioxide. This lower thermal conductivity causes a reduction in the rate at which heat is conducted away from an integrated circuit chip that employs a carbon dioxide insulator, which can result in the catastrophic failure of the integrated circuit.

Air has a dielectric constant of one, which is less than the dielectric constant of carbon dioxide and much less than the dielectric constant of silicon dioxide. Replacing silicon dioxide with air in an integrated circuit reduces the capacitive coupling between signal carrying conductors. Air bridge structures, which are structures consisting primarily of signal carrying conductors surrounded by air in an integrated circuit, are fabricated to reduce the dielectric constant in the conductive structures of an integrated circuit. Unfortunately, since, in an air bridge structure, the signal carrying conductors are no longer embedded in a layer of silicon dioxide, the structural integrity of the integrated circuit is decreased. This problem is especially significant when an integrated circuit fabricated using air bridge structures is packaged as a flip chip,

For these and other reasons there is a need for the present invention.

Summary of the Invention

The above mentioned problems with air bridge structures, closely spaced conductors, silicon dioxide insulators and other problems are addressed by the present invention and will be understood by reading and studying the following specification.

A circuit assembly for fabricating an air bridge structure and a method of fabricating an integrated circuit package capable of supporting an air bridge structure is disclosed. A circuit assembly comprises an electronic chip and a conductive structure embedded in a plurality of materials having a plurality of vaporization temperatures. The plurality of materials are formed on the electronic chip and the conductive structure is coupled to the electronic chip.

A method of forming an air bridge structure comprising a plurality of operations is also disclosed. First, a support structure including interstices is formed on an electronic chip. Next, the interstices of the support structure are filled with a material having a vaporization temperature that is less than the vaporization temperature of the support structure. Conductive structures are embedded in the support structure and the material, and a connective structure is mounted on the support structure. Finally, the material is removed from the support structure.

Brief Description of the Drawings

Figure 1 is a cutaway perspective view of some embodiments of an integrated circuit assembly employing a ribbed support structure of the present invention.

5 Figure 2A is a cross-sectional view of the integrated circuit assembly of Figure 1 along the section line 2.

Figure 2B is a cross-sectional view of the integrated circuit assembly of Figure 1 along the section line 3.

Figure 3 is a perspective view of some embodiments of an integrated circuit assembly of the present invention employing a post support structure.

10 Figure 4 is a perspective view of some embodiments of an integrated circuit assembly mounted on a substrate.

Figure 5A is a simplified schematic of an air-bridge structure supported by conductive posts.

15 Figure 5B is a simplified schematic of an air-bridge structure supported by insulating posts.

Figure 6 is a block diagram of a computer system suitable for use in connection with the present invention.

Detailed Description of the Preferred Embodiments

20 In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific preferred embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be
25 utilized and that logical, mechanical and electrical changes may be made without departing from the spirit and scope of the present inventions. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims.

30 Figure 1 is a cutaway perspective view of some embodiments of integrated circuit assembly 100 of the present invention. Integrated circuit assembly 100, in one

embodiment, includes electronic chip 103, and material layer 106, comprising ribbed support structure 109, fill material 112, conductive structure 115, and interstices 116. In an alternate embodiment, integrated circuit assembly 100 also includes controlled collapse chip connection (C4) structure 118 comprising insulation layer 121, vaporization plug 124, and conductive elements 127 and 130.

Integrated circuit assembly 100 is not limited to use in connection with a particular type of electronic chip 103. Memory chips, such as a dynamic random access memory (DRAM) chips, static random access memory (SRAM) chips, read-only-memory (ROM) chips, and random access memory (RAM) chips, microprocessor chips, logic chips, digital signal processing chips, analog signal processing chips, and application specific integrated circuit (ASIC) chips can all be used in connection with integrated circuit assembly 100.

Material layer 106 is fabricated on the surface of electronic chip 103, and has a plurality of vaporization temperatures. In one embodiment, material layer 106 is fabricated from a plurality of materials in which each of the plurality of materials has a different vaporization temperature.

Material layer 106 includes a structural component, such as ribbed structure 109, and a non-structural component, such as fill material 112. An advantage of using a structural component in the present invention is that the structural component is easily modified to support flip-chip mounting or silicon on substrate mounting of electronic chip 103, without interfering with the layout of the air-bridge structures. Ribbed structure 109 is designed to support the entire weight of electronic chip 103, if electronic chip 103 is mounted using a C4 or flip-chip interconnect. If electronic chip 103 is not mounted using as a C4 or flip-chip interconnect, then the design of ribbed structure 109 is only required to support long run air bridge structures. Ribbed structure 109, in one embodiment, is fabricated by forming a layer of inorganic material, such as SiO_2 , Si_3N_4 , or a low temperature SiO_2 , on the surface of electronic chip 103. The layer of inorganic material is formed to a depth equal to the distance between the surface of electronic chip 103 and the first wiring layer of electronic chip 103. The surface of the layer of inorganic material is patterned and etched to form ribbed structure 109.

Fill material 112 is a non-structural component, and in one embodiment, is a polymer, such as a photoresist or a polyimide. Preferably, fill material 112 is carbon, which has a vaporization temperature of about 400 degrees centigrade, and is deposited in interstices 116 or the etched areas of ribbed structure 109 by sputtering. Fill material 112 is patterned and etched to form a template for the vertical wiring vias and the horizontal interconnect paths of conductive structure 115. In one embodiment, conductive structure 115 is fabricated using the dual damascene process. ("Process for Fabricating Multi-Level Integrated Circuit Wiring Structure from a Single Metal Deposit", John E. Cronin and Pei-ing P. Lee, United States Patent 4,962,058, October 9, 1990, is incorporated by reference.) Alternatively, a single damascene or a subtractive etch process sequence is used to produce conductive structure 115. Conductive structure 115 is formed by depositing a conductive material, such as aluminum, gold, silver, or copper, or an alloy of aluminum, gold, silver, or copper, in the vertical wiring vias and conductive interconnect paths of the template formed in fill material 112. The conductive vias couple conductive structure 109 to electronic chip 103. Excess conductive material is removed by a planarizing process, such as chemical mechanical polishing (CMP), applied to the surface of fill material 112 and ribbed structure 109. After CMP, the surface of fill material 112, ribbed structure 109, and conductive structure 115, including the conductive vias and conductive interconnects, are ready for coupling to C4 structure 118.

Variations of the process described above include fabricating material layer 106 from an organic material or a mix of organic materials and inorganic materials, and patterning and etching the surface of material layer 106 to form a post structure. In addition, the process described for forming air bridge structures and support structures can be repeated to form as many wiring levels as required for the design of a particular electronic chip 103.

C4 structure 118, comprising insulation layer 121, vaporization plug 124, and conductive elements 127, is formed above ribbed structure 109 and fill material 112. Insulation layer 121 is the base of C4 structure 118 and is fabricated from an insulator, such as SiO_2 or Si_3N_4 . After forming insulation layer 121, vias are patterned and etched at via sites 127 and 130. A conductor, such as aluminum, gold, copper, or silver, or an

alloy of aluminum, gold, copper, or silver, is deposited to fill via sites 127 and 130, and the metal is polished back to the surface of ribbed support structure 109 and fill material 112. Finally, a vaporization plug site is etched in insulation layer 121, and a fill material 112, such as carbon, is deposited to form vaporization plug 124. Any excess carbon is removed by polishing back the carbon to the surface of ribbed structure 109 and fill material 112.

Integrated circuit assembly 100 is placed in a furnace to vaporize fill material 112, leaving air bridge-structure 115, C4 structure 118, and electronic chip 103. In one embodiment, the furnace has an O₂ atmosphere heated to about 400 degrees centigrade. In an alternate embodiment, integrated circuit assembly 100 is mounted as a flip chip on a substrate prior to vaporizing fill material 112.

Figure 2A is a cross-sectional view along the section line 2 of the integrated circuit assembly of Figure 1. Conductive structure 115 is formed in and above fill material 112. After fill material 112, which fills interstices 116 formed by ribbed support structure 109, is vaporized, conductive structure 115 is surrounded by a dielectric having a dielectric constant of about 1.

Figure 2B is a cross-sectional view along the section line 3 of the integrated circuit assembly of Figure 1. Support structure 109 having interstices 116 filled with fill material 112 is formed on electronic chip 103. Vaporization plug 124 is formed in fill material 112 and C4 structure 118. In one embodiment, vaporization plug 124 is fabricated from carbon. After heating integrated circuit assembly 100 in an O₂ atmosphere at a temperature of about 400 degrees centigrade, carbon fill material 112 and vaporization plug 124 are vaporized and the gas produced by the vaporization process expands through vaporization plug 124.

Figure 3 is a perspective view of some alternate embodiments of an integrated circuit assembly 300. Integrated circuit assembly 300 comprises electronic chip 303, a plurality of post support structures 306, connective structure 309, and conductive structure 312.

Integrated circuit assembly 300 is not limited to use in connection with a particular type of electronic chip 303. The electronic chips described as suitable for use

in connection with integrated circuit assembly 100 of Figure 1 are also suitable for use in connection with integrated circuit assembly 300.

The plurality of post support structures 306, in one embodiment, is formed from an inorganic material, such as SiO_2 or Si_3N_4 . The processes described above for fabricating ribbed support structures 109 of Figure 1 can be applied to the fabrication of post support structures 306. Alternatively, the plurality of support structures 306 are formed from a conductor, such as aluminum, silver, gold or copper, or an alloy of aluminum, silver, gold or copper. When fabricated from a conductor or an alloy of a conductor, the plurality of post support structures 306 are formed on an insulating base 315 to ensure that the plurality of post support structures 306 do not directly couple to, load, or otherwise electronically interfere with the operation of the circuits formed on electronic chip 303.

To fabricate the plurality of post support structures 306 from a conductor, a layer of material is formed above electronic chip 303. In one embodiment, the layer of material is an organic material, such as carbon. Alternatively, the layer of material is an organic polymer. The layer of material is patterned and etched to form a template for the first level vertical wiring and the plurality of post support structures 306. The template for the vertical wiring and the plurality of post support structures 306 are filled with a conductive material to form the plurality of support structures 306 and the vertical wiring for conductive structure 312. Excess conductive material on the surface of the layer of material deposited above electronic chip 303 is removed by chemical mechanical polishing or a similar planarizing process. An advantage of forming post support structures 306 from a conductor is that post support structures 306 provide a thermally conductive path to the C4 surface.

To form a first level air-bridge conductive segment, a horizontal pattern is patterned and etched. A conductive material, such as gold, copper, aluminum, or silver, or an alloy of gold, copper, aluminum, or silver, is deposited to fill the etched pattern. Excess conductive material is planarized back to the level of the surface of the organic material. The operations described above for forming an air-bridge level are repeated until the fabrication of the final air-bridge level is completed.

After completion of the fabrication of the final air-bridge level, the support structure for the C4 contacts is formed from a layer of SiO₂ or other insulating material. The layer is patterned and etched to leave holes for vertical wiring to the positions of the C4 contacts. A layer of metal is applied to the surface of the SiO₂ and the surface is planarized back to the oxide surface leaving the vertical metal conductors flush with the oxide. This vertical wiring level connects the C4 contacts to the last air-bridge level. Additional openings are etched in the oxide such that all the interior carbon or polymer areas are accessible.

The C4 contacts on the surface of electronic chip 303 are reflowed in an H₂ atmosphere. Electronic chip 303 is flipped and the C4 contacts are joined to a substrate in an H₂ atmosphere. The assembly is placed in a furnace having an O₂ atmosphere at approximately 400 degrees centigrade and the carbon is reduced to gaseous CO₂. If a polymer is used as the fill material instead of the carbon, the polymer is also removed using an O₂ plasma.

If a hermetic packaging is used, the package is back filled with helium to improve the thermal properties of the assembly. If a heat sink is required, it is attached prior to the removal of the carbon support structure.

Figure 4 is a perspective view of some embodiments of integrated circuit assembly 400. Integrated circuit assembly 400 comprises substrate 403, C4 connective structure 406, electronic chip 409, a plurality of post support structures 412, air-bridge conductive structure 415, and heat sink 418. In assembling integrated circuit assembly 400, electronic chip 409 is fabricated for flip chip mounting using C4 structure 406. A plurality of post support structures 412 and an air-bridge structure 415 are fabricated on electronic chip 406. The plurality of post support structures 412 support electronic chip 409 when mounted as a flip-chip on substrate 403. Heat sink 418 assists in cooling electronic chip 409 by conducting heat away from electronic chip 409. If the fill material in which connective structure 406 is fabricated is not removed from integrated circuit assembly 400 prior to mounting electronic chip 409 on substrate 403, the fill material is removed by heating integrated circuit assembly 400. In one embodiment, integrated circuit assembly 400 is heated in an O₂ atmosphere at 400 degrees centigrade. The fill

material is vaporized, and air-bridge conductive structure 415 is surrounded by air having a dielectric constant of about 1. To improve the cooling characteristics of integrated circuit assembly 400, substrate 403 is hermetically sealed and filled with helium or a helium rich gas.

5 Figure 5A is a simplified schematic of air-bridge structure 500 supported by conductive posts 503 and 506. Long run air-bridge conductive structure 509 couples electronic devices embedded in electronic chip 512. Conductive posts 503 and 506 support long run air-bridge conductive structure 509 and C4 connective structure 515. Conductive posts 503 and 506 are terminated in insulators 518 and 521 at the surface of
10 electronic chip 512. An advantage fabricating conductive support posts 503 and 506 from a conductive material, such as aluminum, copper, gold, or silver, or an alloy of aluminum copper, gold, or silver is that conductive support posts 503 and 506 are fabricated at the same time that air-bridge conductive structure 509 is fabricated.

 Figure 5B is a simplified schematic of air-bridge structure 550 coupling devices
15 embedded in electronic chip 553 and supported by insulating posts 556 and 559. Insulating posts 556 and 559, in one embodiment, are fabricated from silicon dioxide. Insulating posts 556 and 559 support long run air bridge structure 562 and support C4 connective structure 565. The fabrication of long run air bridge structure 562 and C4 connective structure 565 are described above in connection with Figure 3 and Figure 4.

20 Figure 6 is a block diagram of a computer system 400 suitable for use in connection with the present invention. System 600 comprises processor 605 and memory device 610, which includes an integrated circuit assembly of one or more of the types described above in conjunction with Figures 1-3. Memory device 610 comprises memory array 615, address circuitry 620, and read circuitry 630, and is coupled to processor 605 by
25 address bus 635, data bus 640, and control bus 645. Processor 605, through address bus 635, data bus 640, and control bus 645 communicates with memory device 610. In a read operation initiated by processor 605, address information, data information, and control information are provided to memory device 610 through busses 635, 640, and 645. This information is decoded by addressing circuitry 620, including a row decoder and a
30 column decoder, and read circuitry 630. Successful completion of the read operation

results in information from memory array 615 being communicated to processor 605 over data bus 640.

Conclusion

5 An integrated circuit assembly having air-bridge structures and a method for manufacturing an integrated circuit assembly having air-bridge structures has been described. An integrated circuit assembly includes structural components that protect the air-bridge structures during flip-chip mounting. A method of fabricating an electronic chip compatible with flip-chip mounting techniques includes the fabrication of ribbed support structures and post support structures. The support structures are fabricated from
10 either insulating or conductive materials.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present
15 invention. Therefore, it is intended that this invention be limited only by the claims and the equivalents thereof.